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PERIDOTITE DIKES NEAR ITHACA, N. Y.

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The country rock at Ithaca consists of Upper Devonian shales and sandstones. The rocks are traversed by two series of well-marked joint planes. One series extends nearly north and south; the other series, east and west. Both series are at right angles to the bedding planes. In general, the joints are more abundant in the shales than in the sandstones.

Many dikes have been discovered in the north-south joint planes, but none have been found in the east-west joint planes. This fact may be accounted for in two ways. The streams, which usually flow either east or west, cross many more north-south than east-west joint planes. Therefore the dikes in the former are more likely to be exposed than those in the latter. However, as the dikes were probably intruded while the rocks were being folded, it seems more probable that the east-west joint planes, which are roughly parallel to the folds, were kept closed by compression during the period of intrusion.

Location and size of the dikes.—The existence of a few dikes near Ithaca has long been known. Professor J. F. Kemp[1] speaks of the three dikes in Cascadilla Creek near the bridge at the entrance to the Cornell campus, and he also mentions the one in Six-Mile Creek above Green Tree Falls. The dike just above the upper bridge across Cascadilla Creek measures about 3 feet. It outcrops on the south side of the gorge; on the opposite side the gorge wall is covered with débris. The other two dikes are each about 2 inches wide. They show on the south wall of the gorge between the upper and lower bridges.

In his *Geology of the Third District of New York*, Vanuxem[2] speaks of four dikes in a gorge near Ludlowville. This gorge is the first one south of the road running east from the village. Two of the dikes referred to by Vanuxem are located near an outcrop of the Tully limestone; the other two are farther upstream, above a high fall over the Genesee shale. The two dikes near the outcrop of Tully limestone, together with a third located near the base of the fall mentioned above, are each about an inch wide.

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[1] J. F. Kemp, "Peridotite Dikes in the Portage Sandstones Near Ithaca, N. Y.," *American Journal of Science*, 3d Ser., Vol. XLII (1891), pp. 410–12.

[2] Vanuxem, *Geology of the Third District of New York* (1842), p. 169.

Above the high fall, instead of two dikes there are four, all showing on the south wall of the gorge. Three of these have been faulted; the fourth does not reach up to the fault plane. The amount of the displacement is about 2 feet. The largest dike is 7 inches wide in its widest part; the others are all small, varying from 1 to 2 inches. There is much branching, and it is doubtful whether more than one of them reaches the top of the gorge wall. Farther upstream is another fall. Above this fall are several small dikes. These are all less than 2 inches wide and appear only on the south side of the stream.

In the gorge just south of the one above mentioned there are five dikes, ranging from ½ inch to 5 inches in width. These dikes may be merely outcrops of some of those which appear in the other gorge; but unfortunately the intervening space is covered with glacial drift, so that the continuity cannot be established.

Just below Taghanic Falls, five small dikes, all less than 4 inches wide, appear on the south wall of the gorge. At least one of them reaches the top of the cliff. A thrust along a bedding plane has displaced these dikes about 20 inches. There is much branching, which often includes fragments of shale thicker than the dikes themselves. On the north wall of the gorge only three dikes were found. Farther upstream, about 100 yards above where the wagon-road crosses, there is a dike about 2 inches wide.

In Glenwood Creek, above the railroad, a dike 7½ feet wide outcrops in the bed of the stream. About 3 feet of the center of this dike weathers like ordinary peridotite; the remainder takes on a schistose appearance when weathered. This peculiar weathering is due to the presence of many vertical cracks along which disintegration progresses rapidly.

Besides the dike in Six-Mile Creek which was mentioned by

J. F. Kemp,[1] there are four others. Two are just below the old pumping-station, and two are about one-quarter of a mile farther upstream. The two near the pumping-station measure 4 and 9 inches respectively; the two above the pumping-station, 3 and 8 inches.

In a quarry at the south end of Hazen Street in the city of Ithaca there are three dikes, ranging from 2 to 6 inches in width. The possibility of these dikes being connected with those near the pumping-station in Six-Mile Creek, and also with some of those in Cascadilla Creek, should not be overlooked. However, direct proof is wanting, and only the fact that they are all in a line nearly parallel with the direction of the joint planes can be cited as supporting the hypothesis that they are connected.

The rocks penetrated by the dikes at Ludlowville, Taghanic, and Glenwood are Genesee shales and Portage shales and sandstones. The dikes in the immediate vicinity of Ithaca penetrate rocks belonging to the Ithaca Group.

Megascopic appearance of the rocks.—The rock is porphyritic, with a dense black aphanitic groundmass, containing phenocrysts of reddish-brown mica and black fibrous masses having the structure of serpentine. The mica is usually in small glistening scales, with an occasional crystal which has a diameter of one-half inch or more. In some cases crystals of olivine may be seen. With a hand-lens, grains of a black metallic mineral (magnetite) are occasionally found. The phenocrysts of serpentine often cover the surface of the weathered rock as black protuberances, sometimes as much as one inch in diameter. These resemble pebbles, but are soft, and when broken, show their fibrous structure.

As the dikes weather they lose their dark color and become a light greenish-gray. On the surface are many mica scales which have faded to a light brown. Further weathering produces a yellow incoherent clay, containing many scales of light brown mica.

Microscopic description of the rock.—Two well-defined phases of the rock are noticeable: (1) porphyritic, (2) non-porphyritic. The porphyritic peridotite contains abundant phenocrysts of olivine, with a subordinate amount of biotite. The olivine phenocrysts are usually altered to serpentine and a carbonate. None of the phenocrysts contain inclusions of magnetite, ilmenite, or perofskite, except such fine grains of magnetite as commonly result from the alteration of the olivine. The groundmass consists chiefly of serpentine with some mica, and small amounts of magnetite, ilmenite, and a carbonate. Much of the mica of the groundmass has lost its original color, and become either green or light brown. Flow structure is very common. The porphyritic phase of the peridotite is confined to the small dikes and to the borders of the large ones.

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[1] *Loc cit.*

The non-porphyritic peridotite was originally composed of olivine and biotite, with subordinate amounts of diopside, magnetite, ilmenite, perofskite, picotite, and apatite. Much of the olivine has been changed to serpentine with the formation of magnetite, opal, and a carbonate. The pyroxene is partly altered to calcite and serpentine. The ilmenite and titaniferous magnetite have been partly removed by solution, leaving a white, cloudy substance, leucoxene. The perofskite has partly changed to calcite and rutile. The relations of the minerals indicate that apatite, ilmenite, magnetite, perofskite, and picotite all belong to an early stage of crystallization; following these came the diopside; and still later the mica and olivine. The mica and olivine were in part pyrogenic, as indicated by their mutual interference during growth.

Mineral composition of the rock.—The following tables give approximately the proportions of the different minerals present, as determined by microscopic measurement:

	I	II
Serpentine	55.881	45.927
Biotite	18.285	29.343
Olivine	0.000	10.178
Ilmenite and magnetite	4.257	6.130
Perofskite and picotite	5.563	6.845
Apatite	tr	0.521
Calcite	15.932	0.873
Diopside	0.000	0.000
	99.918	99.817

The section for No. I was taken from near the center of the Glenwood dike, while the one for No. II was taken from near the margin of the same dike. In both cases the rock is considerably altered.

Neither section shows more than one or two crystals of pyroxene, and careful study does not indicate that any large amount was ever present. For purposes of comparison, the calcite and serpentine may be considered as olivine, for it is apparent, from the form of the grains, that they occupy the position of the original olivine grains. The sum of the serpentine calcite and olivine is, for No. I, 71.713 per cent.; for No. II, 56.978 per cent. If these represent the percentages of olivine in the original rock, the evidence of magmatic differentiation is striking. A similar result is obtained by a comparison of the percentages of biotite in the two sections. The comparison of the magnetite and ilmenite is not a safe means of judging, because No. I shows more weathering than No. II, and much of its magnetite has been removed by solution.

The composition of the other dikes shows considerable range, but all may be classified under the head of mica-peridotite—a name proposed by J. S. Diller[1] for a peridotite of similar composition occurring in Crittenden County, Ky.

Contact phenomena.—Along the contact the shaly sandstone and shales are slightly hardened. Near the Cascadilla and Glenwood dikes the rocks are traversed by an unusually large number of joints. There are many irregular cracks in the sedimentary rocks near the contact of most of the dikes. These cracks are filled with calcite. No new minerals occur in the shales, though near the contact they are abundantly impregnated with calcite and are stained with limonite. The contact is irregular, and frequently the lava has extended in long, thin tongues into the bedding planes. This shows the great fluidity of the magma. The same thing is shown in the small dikes at Taghanic where they cut the Genesee shale. There they frequently pinch and swell very rapidly, and often branch from one joint plane to another where two joints intersect. Frequently branches of a dike pass on both sides of a fragment of shale which is thicker than the combined width of the two branches of the dike. The great fluidity of the lava in such cases does not necessarily mean an excessively high temperature, as basic lavas liquefy at comparatively low temperatures. The meager contact effect is explained by thinness of dikes and their low fusion point.

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[1] *American Journal of Science*, 3d Ser., Vol. XLIV (1890), pp. 286–89.

The olivine.—Not a single complete grain of olivine was seen in any of the slides, and in several slides it was difficult to find more than a few small fragments of the mineral imbedded in a network of serpentine. The olivine was colorless and contained numerous fine, dust-like inclusions of a dark color, and occasionally grains of a carbonate. Usually the shape of the masses of serpentine indicated that the olivine was in rounded or irregular grains; but occasional sections were found which had sharp crystallographic outlines. Mica scales were found within the serpentine derived from olivine, and some of the grains of serpentine were surrounded by mica. The contact between the two minerals was usually irregular, even when the same grains showed sharp crystallographic outlines elsewhere. This indicates that the two minerals were in part pyrogenic. The olivine enveloped grains of magnetite, perofskite, apatite, and picotite, indicating that these minerals belonged to an earlier stage of crystallization. During the alteration of olivine to serpentine much magnetite was formed. This magnetite occurs in small grains, sometimes so abundant as to make the serpentine appear black. Many of the irregular patches originally occupied by olivine were filled, either wholly or in part, by carbonate. This was doubtless partly dolomite, resulting from the removal of a part of the magnesia and silica, the carbonation of the remaining magnesia, and the infiltration of calcium carbonate. Probably in some cases the magnesia was largely removed, for when the rock was treated with weak HCl it effervesced vigorously for several minutes, indicating the presence of much calcite.

Serpentine.—Serpentine is the most abundant mineral in the rock. It occurs, as pseudomorphs after olivine or pyroxene, in rounded or irregular masses averaging 0.064^{mm} in diameter. It is frequently found inclosing fragments of the unaltered olivine. Two kinds occur: (1) a yellowish fibrous variety, (2) a green fibrous variety. The yellow serpentine has its fibers arranged nearly parallel, and hence its double refraction is considerable. The extinction is parallel. In converging light a biaxial interference figure appears. The axial plane lies at right angles to the fibers, and the black hyperbolas barely remain in the field when a No. 9 objective is used. A faint pleochroism is sometimes noticeable, ranging from green parallel to the fibers, to brown at right angles to them. The elongation of the fibers is parallel to **c**. Occasionally the yellow serpentine appears granular rather than fibrous. Closely related to the yellow serpentine in optical properties is the nearly clear variety found in the cracks where the original olivine granules were apparently fractured by shearing. The fibers always have the same optical orientation, and stand at right angles to walls of the cracks.

The green serpentine is frequently traversed by fibers, giving a bright interference color. Radiating from these fibers are others which show little double refraction; inclosed by these are light green patches which have low interference colors.

The serpentine contains an abundance of magnetite and a carbonate. The light green patches are almost free from magnetite, except for a small amount of very fine dust. As alteration progresses, the fibers become cleared of magnetite, which is evidently removed by solution, and is taken first from the large cracks where the alteration began. During alteration the amount of serpentine gradually diminishes, and the amount of carbonate increases. In some cases a clear isotropic substance is enveloped by serpentine. This substance, which has a low index of refraction, is probably opal, as the formation of opal and magnetite is a frequent accompaniment of the change of iron-bearing olivine to serpentine. The presence of the carbonate is doubtless due, in part, to infiltration of calcite, in part, to the carbonation of magnesia with the freeing of silica.

Mica.—The mica occurs in light brown crystals averaging 0.04^{mm} in diameter. The mica has a weaker absorption than ordinary biotite, and probably has the composition of phlogopite. Plates cut at right angles to the cleavage frequently show a rim with a reddish-brown color. The same color often shows along the cleavage planes. This colored rim is probably the result of alteration with oxidation of the ferrous iron. As alteration proceeds, this coloring-matter is removed, and the mica becomes lighter colored than it was originally. Frequently three zones of color can be recognized in the same crystal: an inner yellowish-brown zone, surrounded by a zone of reddish-brown color, and this in turn surrounded by a zone which is almost colorless. These zones are optically continuous; but all differ in pleochroism and double refraction. The pleochroism of the light-brown mica ranges from pale green to yellowish-brown; that of the highly colored border, from green to reddish-brown; and that of the clear margin, from colorless to light brown. The double refraction is high, but as the mica begins to alter, the interference colors appear ragged and are less intense. The extinction angles are usually small. The interference figures range from distinctly uniaxial to biaxial with a very small axial angle. Between the scales of altered mica there are frequently lenticular masses of a carbonate. The mica often alters to chlorite. This alteration was most commonly met with in the porphyritic variety of the rock. In several cases slender needles occur at the contact of an altered mica crystal and serpentine. These needles extend radially from the mica into the serpentine, and are too small to give much indication of their optical properties, except the fact that they are strongly double-refracting, with nearly parallel extinction. They are probably an amphibole.

The mica contained inclusions of magnetite, perofskite, apatite, and picotite, showing that these minerals belonged to an earlier stage of crystallization. There were a few inclusions of serpentine, having a structure which indicated that the original mineral was olivine. Sections in the basal plane showed many fine, dust-like particles of a brown or black color.

There were many large crystals which showed crystal outlines either wholly or in part. The contact between these and the olivine indicated that both were growing at the same time. The mica sometimes extends into irregular embayments in the pyroxene.

Besides the micas described above, there are irregular jagged or shredlike plates of a much smaller size. These surround the alteration products of the olivine, and they may be secondary micas.

Pyroxene.—The pyroxene is a clear, non-pleochroic mineral, containing inclusions of magnetite and perofskite. It is thus seen to belong to a later stage of crystallization than the magnetite and perofskite.

The extinction angles range from 35° to 40°, and the axis of least elasticity which lies in the acute angle β makes an angle of 36–37° with the prismatic cleavage. In converging light the mineral is seen to be biaxial, with a small axial angle. Rectangular cleavage blocks show the emergence of an optic axis. This fact, taken with the relation of the axis of least elasticity to the prismatic cleavage, indicates that the mineral is the variety of pyroxene called diopside. A trace of a pinacoidal parting shows on sections normal to the prismatic cleavage. The alteration gives rise to a carbonate which often surrounds the crystals and extends along the cleavage cracks. Some of the grains of serpentine with fibers at right angles to each other are doubtless the result of alteration of pyroxene.

Magnetite and ilmenite.—Magnetite is scattered throughout the rock, sometimes in the form of minute grains in the serpentine, and at other times in octahedrons or irregular grains which are as much as 0.03^{mm} in diameter. Cross-sections are quadratic, trigonal, or irregular. The grains in the serpentine are usually very small and result from the alteration of olivine, or, less commonly, pyroxene. As alteration progresses, these fine grains are removed by solution. In the alteration of some of the irregular grains and crystals a white, semi-translucent substance, leucoxene, is produced, indicating the presence of titanium in the form of titaniferous magnetite or ilmenite. Almost all the original crystals appeared to be titaniferous; the only pure magnetite being that resulting from the alteration of olivine and other ferro-magnesian minerals.

Apatite.—Apatite occurs in irregular grains or in slender prisms, which sometimes show a basal parting. It occasionally occurs as inclusions in the olivine or biotite; at other times the grains or crystals are scattered about between the crystals of mica. The apatite is a clear, colorless, non-pleochroic mineral, with a high index of refraction and a low double refraction. Basal sections show a uniaxial interference figure. No alteration takes place, but the surface of the crystals is often pitted.

Perofskite and picotite.—The perofskite occurs in yellowish-brown crystals and grains. The cross-sections are varied, being diamond-shaped, trigonal, hexagonal, or irregular. Many of the irregularities are due to aggregations of crystals. Some skeleton crystals and some incipient forms of growth occur. The index of refraction is high, and the sections are usually entirely isotropic between crossed nicols. The sections are often traversed by irregular cracks, sometimes showing slight alteration. In one case a grain of perofskite which had been included in apatite was partly altered to a carbonate (calcite), containing minute fibers of a clear, non-pleochroic mineral, with high double refraction and nearly parallel extinction. This was probably rutile. Similar alteration was frequently seen elsewhere, and associated with the rutile was leucoxene. Scattered through the sections is a light-yellow mineral, with a slightly lower index of refraction than perofskite. This is probably picotite. It is entirely isotropic between crossed nicols.

Chlorite.—Chlorite is only important along the contact of the dike with the shales, though it also occurs at the contact of mica and serpentine. Doubtless the chlorite is the result of the action of aluminous solutions on the ferro-magnesian mineral olivine.

At right angles to the polarizer the fibers of chlorite are almost colorless, having only a slight yellowish tinge. Parallel to the polarizer the fibers have a bright green color. Basal sections usually have a greenish color. They show a biaxial interference figure with a small axial angle; and the sign is positive. The extinction angles are very small. The fibers are often bent and broken, though few show any crushing of pressure. The variety is probably prochlorite.

Age of the dikes.—The age of the peridotite dikes is a difficult question to solve. That they are younger than the Upper Devonian rocks through which they have been intruded is perfectly evident. During the field investigations certain facts were discovered which may help to fix their age more definitely. The sedimentary rocks have been folded into anticlines and synclines. The age of these folds has been discussed by Mr. E. M. Kindle:

> It appears certain that the comparatively insignificant structural features which have been described are of the same age and origin as the great open folds of the northern Alleghenies. In the quadrangle cornering with the Watkins Glen quadrangle on the southwest are folds whose arches, if restored, would rise 2,500 feet above their troughs. Less than twenty miles to the south of the Watkins Glen quadrangle another great fold shows a crest of similar or greater elevation. From theoretical considerations it would appear improbable that the effects of the epirogenic forces which have developed structures of such magnitude should terminate abruptly at the northern edge of the highly folded belt. Instead of abrupt change from highly folded to monoclinal or nearly horizontal structure, we find the mountain flexures subsiding gradually into the low, gentle swells which have been described. This may be illustrated by a comparison of the maximum dips exhibited by the anticlinal folds encountered between South Mountain in Bradford County, Pennsylvania, and the southern end of Lake Seneca. Eighteen

miles south of the Watkins Glen quadrangle runs the axis of the Towanda anticline between two synclinal mountain ridges—Mount Pisgah and South Mountain. Dips of 70° or more have been observed on the south side of this anticline, but the average dip for the belt of maximum inclination is approximately 40°. The dips of the north limb of this fold are very much lower than the south dips. The writer, although familiar with the region, has not observed any dips which will exceed 20°, and the dips in the zone of maximum inclination will probably not average more than 15°. It is noteworthy that the great excess of the south dip over the north dip of this fold is a characteristic common to nearly all folds of the Watkins Glen quadrangle.[1]

Accompanying the folding were movements along the bedding planes; some minor thrust faults were formed. These two forms of displacement pass into each other. Willis discusses the conditions under which displacements along bedding planes take place, in his article on "The Mechanics of Appalachian Structure:"

> The transmission of pressure through a folding stratified mass may be stated as follows: So long as the stratification is parallel to the original direction of pressure, the force is transmitted as a whole and tends to reduce the volume of the mass; when the strata are inclined to the direction of pressure, the thrust is resolved into two components, the one parallel to the bedding, the other perpendicular to it; the former produces movement when it overcomes the friction on the bedding planes, the viscosity of the strata and any opposing force, as the load; the latter becomes active when it causes some part of resisting mass to move.[2]

It was doubtless the thrust parallel to the bedding planes which produced the displacements under discussion. Where the cohesion between the strata was less than the strength of the rock, the movement took place along the bedding planes; where the cohesion was greater than the strength of the rock, a fracturing of the beds resulted, and movement took place along the fracture plane. Since these displacements have a bearing on the history of the dikes, a few of them will be discussed here. On the south limb of the Watkins anticline, in Six-Mile Creek, is a small thrust fault which passes into a displacement along the bedding planes. In Shurger's Glen there is a similar fault connected with the anticline which crosses Lake Cayuga near Shurger's Point. In this case the fault passes into displacements along several adjacent bedding planes. On the north limb of this same anticline there has been a movement along a bedding plane. This movement has faulted four dikes on the south wall of Taghanic Gorge and three dikes in a gorge east of Ludlowville. The amount of displacement of the ends of the dikes is only about 2 feet, and the movement is largely confined to a single bedding plane. The dikes are nearly at right angles to the axis of the fold, and hence eighteen inches can hardly be taken as the measure of the amount of movement. Probably the movement was nearly parallel to the dikes, and, if so, the amount of actual displacement might be several times the distance between the severed parts of the dikes. Slickensides are not noticeable, but the bedding plane is occupied by a thin layer of pulverized shale. At first the possibility of the dikes having passed for a short distance along this bedding plane was considered. This theory was discarded, because all the dikes showed the same displacement; and the clay between the strata did not contain any of the mica scales which are so prominent in the clays derived from the disintegration of the dikes.

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[1] "A Series of Gentle Folds on the Border of the Appalachian System," *Journal of Geology*, Vol. XII, No. 4 (1904), p. 287.

[2] Willis, *Thirteenth Annual Report*, U. S. Geological Survey, Part 2 (1891–92), p. 246.

The sequence of the earth movements in this region appears to have been as follows: folding with the development of joint planes; the intrusion of the dikes and their consolidation; renewed folding, accompanied by minor thrust-faulting and movements along bedding planes. The relation of the folds of this region to those of the Appalachian Mountains makes it clear that the periods of folding must have been the same. It follows, then, that the dikes are probably younger than the earliest period of folding and older than the latest. This would fix the date of the intrusion near the close of the Paleozoic.